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Title: Designing a Competitive Ancillary Services Power Market

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Abstract

In a deregulated electricity market, the system operator has the tough task of matching the schedules and demand in real time. In order to maintain the system security and reliability, essential services called ancillary services are required to be procured to maintain the voltage and frequency of the system. In this work, an attempt shall be made to design a market for ancillary services and test it on a sample system, through an algorithm so as to optimize the cost or improve the social welfare.

Keywords: Ancillary Services, Competitive, Power Market, Voltage control

Contents

Sl No.	*Description*	*Page No.*
1	**Introduction**	**4**
2	**Literature Review**	**6**
3	**Description of Broad Area /Topic**	**10**
4	**Objectives**	**11**
5	**Methodology to be adopted**	**11**
6	**Expected Outcome of Research**	**11**
7	**References**	**12**

1. Introduction:

Introduction of competition in the Electricity sector under regulatory oversight has been the hallmark of Electricity Act 2003. The Indian power sector is undergoing a restructuring process with unbundling of generation, transmission, and distribution services being carried out in different states. Regulatory bodies at the Central level i.e. Central Electricity Regulatory Commission (CERC) and SERC at the state level have been formed to take care of the regulatory aspects of the ongoing restructuring process. The Unbundling process has created entities like Generation companies, transmission companies and distribution companies in different states. As deregulation and restructuring are happening , gradually creating multiple entities, the role of matching schedules and demand needs to be assigned to system operators, as vertical integration is gradually being dismantled. Regional Load Dispatch Centres (RLDCs) and State Load Despatch Centres are run by the Transmission Utilities.They prepare dispatch and drawal schedules for generators and beneficiaries, respectively, on a day-ahead basis with respect to the availability of generation and forecasted demand considering system security and reliability. RLDCs are also responsible for maintaining a balance between generation and demand in real-time operation, and for providing reactive power support. The RLDCs in the Indian context behave like a system operator.

In a competitive electricity market, the system operator (SO) is required not just to support the main transactions of energy and power but also to arrange or procure certain services required for maintaining the security and reliability of supply. These so-called ancillary services are required for maintaining acceptable frequency and voltage levels in the system, providing a reserve to ensure secure operation of the system, handling emergency situations such as black start. The literal meaning of the word *ancillary* is providing support or help. Despite their considerable cost, these services are important for bulk-power reliability as well as for the support of commercial transactions. In a vertically integrated market structure, these services form an integral part of the responsibility of the electricity company, whereas a separate mechanism exists for ancillary services in a deregulated electricity market.

1.1 The Indian Power System

The Indian power system has an installed capacity of 1,67,400 MW (as of Dec 2010) and is meeting a peak demand of 108,866 MW. It consists of five regional grids: the Northern Regional grid (NR), Western Regional grid (WR), Eastern Regional grid (ER), Southern Regional grid (SR), and North Eastern Regional grid (NER). The power system, in each region, is being operated and managed securely by regional load dispatch centers. The RLDC acts as system operator. Presently, the central transmission utility, Power Grid Corporation of India Limited (PGCIL), is responsible for the operation of RLDC until a separate organization or

institution is formed. Three of the regions – that is, NR, WR, and SR – suffer from severe power deficits, while ER is having surplus generation of about 2,500 MW and NER is having marginal surplus based on hydro reservoir levels. The regions are connected to each other through asynchronous links (HVDC back to back) as well as synchronous links (HVAC links) to enable exchanges when the surpluses available. To date, ER, NER, WR, and NR are operating synchronously, except SR, which is connected to ER and WR asynchronously. ER-WR, NR-WR, ER-NER, and ER-NR are connected through 400 kV or 220 kV AC lines. The prevailing situation indicates that the capacity of central generating stations (CGSs), inter-state generating stations (ISGSs), and independent power producers (IPPs) have been allocated to different states on a percentage sharing basis, in a particular region. Thus, the states are known as beneficiaries. Each state has its own transmission system, managed and operated by the respective state load dispatch centers (SLDCs). In some states, private players are operating the distribution utilities and acting as separate load-serving entities (LSEs). Based upon the forecasted demand of LSEs, the SLDCs forecast their demand on behalf of a beneficiary to the RLDC.

The scheduling and dispatch, in the current power industry scenario in India, is illustrated in RLDCs prepare the dispatch and drawal schedule for generators and beneficiaries based on their availability and forecasted demand along with the consideration of transmission constraints and system security. In real-time operation, the generators and beneficiaries may not stick to the schedule prepared by RLDC. Therefore, to maintain grid discipline, a frequency linked balancing mechanism has been implemented.

Consumers, generating units and system operators expect an appropriate standard for the frequency and the voltages across the system. Such a standard refers to the system services. In practice, the global frequency and the local voltages depend on the balances between consumption and generation of active and reactive powers across the power system. However, these balances are constantly perturbed by users. Therefore, some users have to act on the active and reactive power balances in order to improve the frequency and voltages, instead of perturb them. Such contributions by the users are called ancillary services. Users hence can benefit from system services, consume them, provide ancillary services or do all of these. The developments in information technology, power electronics and electricity markets forces all users to face their double responsibilities as a consumer of system services and a provider of ancillary services. However, to grasp fully this opportunity, the users need an appropriate framework to manage ancillary services. Unfortunately, current frameworks are disparate, and none can claim to be fully efficient. As capacities for energy and Ancillary Services(AS) are physically linked and since AS often involve the production or consumption of energy, markets for energy and ancillary services present numerous similarities. A lot of attention has thus been concentrated on defining pricing mechanisms to coordinate ancillary services with the markets for electrical energy in a centralised unit commitment structure. However, by focusing on centralised pricing and assuming that a spot market combined with bilateral contracts is the best model, one misses

some aspects of the AS markets, which are not only crucial but also very different from what one finds in energy markets. Difficult issues that have not received enough attention include for example the procurement of AS in the long-term, a coordinated clearing of markets for energy and reserves with a decentralised unit commitment, or an allocation of the cost of AS that gives proper incentives.

2. Literature Review

Ancillary services are one of the pillars of market design. Ancillary services are those functions performed by the electrical generating, transmission, system-control, and distribution-system equipment and people that support the basic services of generating capacity, energy supply, and power delivery (Hirst & Kirby, 1995). The Federal Energy Regulatory Commission (FERC 1995), in its Notice of Proposed Rulemaking (NOPR), defined ancillary services as "those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system." Unbundling generation and transmission services is likely to promote economic efficiency. Such unbundling will allow customers to choose those services that they need and will require customers to pay for the services that they use. Similarly, unbundling will encourage competition among suppliers and thereby lower the costs of these services. Overall, unbundling should increase customer choice, promote competition, and provide more accurate price signals to both suppliers and consumers of these services. The overall cost of ancillary services is roughly 6 to 20% of total generation and transmission costs, equivalent to almost $14 billion a year (Kirby and Hirst 1996). Unbundling for its own sake has no value (Hogan 1995a). Unbundling should proceed only to the point at which the value of further unbundling no longer exceeds the cost of unbundling. At some point, increasing transaction costs and the loss of economies of scope will outweigh the benefits of further unbundling. Also, some functions may be purchased separately from suppliers (e.g., dynamic reactive support and black-start capability) but remain bundled to customers.

Different countries or regions adopt different methods for ancillary services management. In some countries, ancillary services are procured through a competitive market mechanism alongside the energy market. The markets for energy and ancillary services clear simultaneously with clearing volumes and prices for energy and ancillary services, respectively. Some countries or regions adopt a regulatory approach towards ancillary services procurement and remuneration.

Fundamental issues in the design of markets for ancillary services (AS)

(1) choosing the entity responsible for AS procurement;

(2) matching demand and supply

(3) choosing the relevant procurement methods

(4) defining the structures of offers and payments

(5) organizing the market clearing procedure

(6) avoiding price caps

(7) providing efficient incentives assessing the procurement method

Various regulatory bodies across the world have evolved their own systems based on the prevailing structure of electric supply system and operational practices in the country. However common thing in all the systems is that either an Independent System Operator of Transmission System Operator has been entrusted the job of procurement of these services.

Different countries have different mechanisms for procurement of ancillary services. **Liu, Y. Alaywan, Z. Rothleder, M. Liu, S. Assadian, M. (2000),** have shown that the California Independent System Operator procured these services sequentially from the highest quality service market to the lowest quality one. The cost of procurement for each market is based on a market clearing price which is the highest accepted bid price in that market. The sequential method does not necessarily result in a minimized overall procurement cost. In this paper, a rational buyer's algorithm that has been in production since August 18, 1999 is introduced. By shifting requirement from the lower quality service market to the higher quality service market, this algorithm performs an exhaustive search to find the minimum-cost procurement plan while keeping the total requirements for all markets unchanged. The issues on feasibility and performance of the algorithm are discussed, a numeric example is given, and real-time operation result data that show significant saving of the overall cost are included.

This rational buyer's algorithm is good, but has a few limitations. It reduces the overall procurement cost of the ancillary services. It is able to find optimal solutions within the framework of the market rules. The first one month real-time operation results have shown that while saving is significant, the execution time performance of the rational buyer's method needs to be improved. When the number of bids is higher that it would require very high execution time. The run-time for the worst case makes the method impractical.

(Zhong, 2001) proposes a **c**ompetitive market framework for reactive power wherein a reactive power bidding structure is proposed and the reactive power is provided by generator is settled at a uniform market price.

Siddiqui S. Afzal, Marnay Chris, Khavkin Mark (2001) have shown that typically in a competitive electricity market the vertically integrated utility that were responsible for ensuring system reliability in their own service territory, cease to exist. The burden falls on an independent system operator(ISO) to ensure that enough ancillary services are available for safe , stable and reliable operation of the grid, typically defined as compliance with officially approved engineering specifications for minimum level of AS. In order to

characterise the behaviour of market participants,(generators, retailers and ISO) in a competitive electricity environment with reliability requirements, spot markets for both electricity and AS are modelled. By assuming that each participant seeks to maximise its wealth and that all markets clear, we solve for the optimal quantities of electricity and AS trade in the spot market with all participants, as well as the market clearing prices for each.

In the last few years there has been a worldwide trend toward restructuring the electricity supply industry and consequently energy markets were created. In this competitive environment ancillary services play a very important role to withstand the security level during the electric power system operation. **Pereira, A.J.C. Alves, J.P. Vale, Z.A. Machado e Moura, A. Pinto, J.A.D.(2004)** have covered study and analysis of the ancillary services dispatch in a competitive electric market. The simultaneous optimization technique and the genetic algorithm are used to obtain the results, considering a daily load diagram scenario. Different probability values for the use of the ancillary services were considered as well as the minimum limits. Finally, the solutions produced by the two formulations were compared and some important conclusions that provide a contribution to a better understanding of the competitive electricity market are pointed out.

The rational buyer's algorithm as a computational method adopted by the California System Operator is also explained by **Delvecchio, G. La Scala, M. Pugliese, P. Sylos Labini, D"., (2005).** This method is used to minimise the total procurement cost of the reserve power purchased by means of auctions. The method in this paper proposes to apply a genetic algorithm to the traditional rational buyer method and allows the independent system operator to minimize the total procurement cost and also to reduce the computation time. The new method turns out to be very useful, especially when auctions follow one another at a fast pace with a high number of bidders.

Papalexopoulos A., (2007) reiterates that ancillary services are essential to the reliability and security of power system operation in any competitive electricity market environment. This paper discusses various AS market design options for procuring, pricing and settling Ancillary Services via competitive auctions by an Independent System Operator (ISO). The author also discusses problems and potential solutions associated with these market design options based on actual experience of operating ISOs. These problems include problems based on price volatility and spikes and price reversals for the various components of the Ancillary Services that can be create perverse incentives in the marketplace. Further, the author elaborates on the design that has been proven so far based on practical experience to be the most efficient.

As per **Khaitan, S.K., Li Yuan, Liu Chen-Ching (2008)** when there is an ancillary services market the cost of next MW at any node or load bus remains the same when there is no congestion. On the other hand, there is differential price or LMP when the transmission system is congested and the one causing congestion is paying more. LMP is a standard way for congestion management. Therefore, load sensitivity studies are important to reflect the

impact of load increase at a node on the system in terms of LMP. The above factors of uncertainty and importance of LMP motivated the modelling of the LMP Calculation in a market environment through a neural network configuration. Genetic algorithms are a category of evolutionary algorithms which are used for optimisation problems. These techniques are not very effective against estimation problems. So Khaitan et al have proposed that Artificial neural networks can be very attractive for estimation of LMPs under the situation of uncertainty and missing information. ANN Models are good universal function approximators and easy to train. Neural networks are the most robust machine learning tools for estimation. They take time to train but once trained they can process and estimate output in real time.

Pindoriya, N.M., Singh S.N., Singh S.K., (2008), have studied Spinning Reserves and its effect to maintain power system reliability following a major contingency. An accurate short term prediction of Day Ahead SR requirement helps the ISO to make effective and timely decisions in managing the compliance and reliability of the power system. Moreover based on the forecasted information, market participants can derive the optimal bidding strategies for Day Ahead SR market. An adaptive wavelet Neural network (AWNN) is proposed in this paper for short term prediction of day ahead SR requirement in the California ISO (CAISO) controlled Grid. The forecasted results are presented and compared with artificial neural networks (ANN) model and CASIO published forecast results. It is suggested that AWNN performs better than ANN and CAISO forecast results.

Parida, S.K., Singh, S.N.; Srivastava,S.C.; Chanda, P., Shukla A.K.(2008), discuss the mechanism adopted for the provision of frequency regulation service in India, which is done through the Unscheduled Interchange Mechanism. Though the generators are the sole providers to maintain the instantaneous between generation and demand, sometimes they get losses due to the imposed regulation. If there would be no regulation, then there might be collusion through which generators get huge benefits. The deviation in the drawal schedule of each beneficiary in real time has been decided by SLDCs, based on a comparison of UI rate with incremental cost of its own generating units, and the demand requirement. The method adopted does not consider any reliability criteria for frequency regulation service provision, which is an important mandatory requirement for the system. It is mandatory for all generators to operate under free governor mode of operation as per the CERC Regulation mentioned in IEGC. No charges paid for keeping reserve of operating under FGMO continually which sometimes restrains the generators.

(Puneet Chitkara, 2009) The need for a market based approach for reactive power procurement has been recognised by FERC. Due to the localised characteristic of reactive power, regulatory mechanisms are necessary to mitigate the possibility of holding market power by generators. The Regulator is responsible for devising the regulatory mechanisms that provide the incentive to generators to supply reactive power while preventing the abuse of market power. This paper proposes a mathematical model to simulate the strategic behaviour of generators supplying reactive power while considering the system operators

schedule. The proposed method can be used by Regulator to simulate the market behaviour in the reactive power supply. It is also studied how the Regulatory Polices affect the market behaviours. An alternative price cap method has been proposed and tested in the numerical example to mitigate the effect of strategic behaviour of generators in reactive power procurement by the system operator. The numerical examples are tested on a Nordic 32-bus system.

Electricity market players operating in a liberalized environment requires access to an adequate decision support tool, allowing them to consider all the business opportunities and take strategic decisions. Ancillary services represent a good negotiation opportunity that must be considered by market players. For this, decision support tools must include ancillary market simulation. **Vale, Z.A. Ramos, C. Faria, P. Soares, J.P. Canizes, B. Khodr, H.M, (2010)** This paper proposes two different methods (Linear Programming and Genetic Algorithm approaches) for ancillary services dispatch. The methodologies are implemented in MASCEM, a multi-agent based electricity market simulator. A test case concerning the dispatch of Regulation Down, Regulation Up, Spinning Reserve and Non-Spinning Reserve services is included in this paper.

3. Description of Broad Area of Research/Topic

For a restructuring Indian power sector, a preliminary structure of the market and power exchange has already been proposed by Central Electricity Regulatory Commission. The success of this market will be strongly tied to the proper provision of ancillary services, particularly frequency and voltage control. I propose to describe the current status of ancillary services mechanisms and key issues that need to be addressed. Until a few years ago, only a few electrical engineers and system operators in electric utilities knew what ancillary services were. Because of increasing competition in, and changing regulation of, the U.S. electricity industry, ancillary services are now an important issue. The topic is important for the vertically integrated utilities that generally supply these services; for the utilities (such as municipalities and cooperatives), large industrial firms, and power marketers that must buy these services to effect power purchases; for independent power producers that might be able to provide some of these services; for state and federal regulators that must decide whether and how to unbundle and price these services; and especially for electricity consumers, whose continued reliability of service depends on ancillary services. All users of an electrical Power System expect that the frequency and voltages are maintained within acceptable boundaries at all times. Some participants, mainly generating units, provide the necessary frequency and voltage control services, called ancillary services. Since these participants are entitled to receive a payment for the services provided, markets for ancillary services have been developed along with the liberalisation of electricity markets. However, current arrangements vary widely from a power system to another. The needs of users can be expressed as appropriate reliability, power quality and power system utilisation. System

services, by controlling reactive and active power balances, help to meet these three objectives. Such a comprehensive assessment exhibits several advantages:

(a) stakeholders can quickly grasp the issues related to ancillary services;

(b) participants benefit from a standardised method to assess their system;

(c) solutions are proposed to improve current arrangements; and

(d) theoretical limitations that need future work are identified.

The aim of the ancillary services market is system security. For e.g. the aim in this thesis is on voltage control and so the measure of this security is the proximity to the voltage collapse in terms of the largest load change that the power system may sustain from a well-defined operating point. The ancillary services market therefore consists of three stages: preparedness, assessment and actuation.

4. Objectives

- Defining the needs for frequency and voltages, and identifying key issues and challenges in India for ensuring power system security
- Classification of Ancillary Services
- Procurement and Remuneration of Voltage Control Ancillary Services
- Market Mechanism for Voltage Ancillary Services

5. Methodology to be adopted

- An analysis of National /International ancillary services power markets
- Developing an algorithm for a competitive procurement of voltage control ancillary as well as spinning reserve services
- Modelling of a network and conduct various analysis like load flow studies, reliability studies etc.,
- Using Simulation tools such as MATLAB, use the proposed technique on a small test system (e.g. a 9 bus system)and then it can also be applied to larger system.

6. Expected Outcome of the Research

A framework for ensuring power system security in a competitive electricity market shall be developed, based on market for ancillary services. In this research work, the detailed classification, procurement, and remuneration methods of the ancillary services provision shall be discussed through designing of a model and Simulating the Model. An algorithm shall also be written based on the market rules. These rules provide the analytical basis for

the algorithm that determines which ancillary service offer should be accepted to system security for least overall cost. An algorithm shall be developed by using the contingency based modelling approach. The approach shall be used on a nine bus test system. Clearing the ancillary services market is a difficult optimisation exercise. This algorithm shall select reactive power offers so as to optimise power system security for least overall cost.

Based on the Literature Review conducted it is pertinent to mention that many authors have used the Genetic Algorithm, Artificial Neural Networks, Fuzzy Dynamic programming,, Non Linear Programming etc.,

Based on the above discussions a simple, easily understandable and implementable mechanism shall be suggested for Procurement of Ancillary Services "The mechanism can be implemented without any elaborate metering arrangements and shall go a long way and a step forwards towards market mechanism.

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